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Growth performance and condition of oysters (*Crassostrea gigas* and *Ostrea edulis*) farmed in an offshore environment (North Sea, Germany)

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ABSTRACT

Aquaculture production plays an increasingly important role to meet the global demand for aquatic products and expands continuously. Most mariculture organisms are produced in coastal areas, where space is scarce and user conflicts exist. For extensive cultures farming off the coast at offshore sites could be a solution to eliminate these problems and facilitate further expansion of environmentally sustainable aquaculture. The aim of this study was to examine the biological adequacy of two candidate species for ostreiculture, the Pacific oyster *Crassostrea gigas* and the European flat oyster *Ostrea edulis*. Growth rates, condition and mortality in offshore environments were investigated by transferring oyster spat of both species to 4 different sites in 2004 and 2007. Samples were taken every six to eight weeks from April to October and length, width, height and dry mass were measured as well as the Condition Index (CI = dry mass meat · 100/dry mass shell) was calculated. Results show that both oyster species grow successfully in a high-energy environment. Mean growth rates are similar to those measured in individuals from coastal habitats (wild banks and cultures) and the CI shows seasonal variation in both species. The survival rate for both species was >99% in 2007. However, in the previous trial in 2004 a high mortality rate was observed for *O. edulis* at one single site at the end of the experiment. Differences were observed in the increase of shell length and dry mass between sites and size classes. Taking these results into account site-selection criteria for different offshore locations are presented. We conclude that offshore cultivation of oysters will be successful if site-selection criteria are examined carefully when choosing a location for offshore aquaculture.

1. Introduction

Aquaculture is the fastest-growing sector of food production worldwide (FAO, 2009). The production of marine organisms mainly takes place in sheltered areas or embayment of the coastal sea (Buck et al., 2003; Firestone et al., 2004). However, in coastal areas space for all kinds of utilization is scarce, thus user conflicts exist and permanently increase (Buck et al., 2004; Wirtz et al., 2002). Intensive seafood production (e.g. fish or shrimp) often generates environmental stress caused by chemicals, eutrophication and impacts on benthic communities (McElwee, 1998). Therefore, in most nearshore areas the ecological carrying capacity sets limitations to massive expansions of intensive aquaculture activities (Troell et al., 2009). Extensive cultivation methods and extractive culture species with modest service needs offer the chance to move to offshore areas, away from socio-economic conflicts and coastal pollution (Krause et al., 2003) and still have an economic potential (Buck et al., 2010). Offshore or open-ocean aquaculture stands for the move of aquaculture operations from sheltered nearshore areas to more exposed environments where high wave action and strong currents exist (Ryan, 2005). However, due to the strong exchange and dilution effects of the water column in these high-energy environments, the water quality, the major element in aquaculture operations, is regarded to be very good (BSH 2006; Takayanagi, 1998).

Less user conflicts and higher wind speeds in offshore regions also enhance growing interests in offshore wind farming. Worldwide wind farms in offshore areas are being planned or already under construction (Gierloff-Emden, 2002). Following the multi-use concept of the Alfred Wegener Institute for Polar and Marine Research (AWI) and the Institute for Marine Resources (IMARE) foundations of offshore wind turbines can be used for additional purposes. Therefore, aquaculture installations can be attached to or installed between turbines within a wind farm (e.g. Buck & Krause 2011; Buck et al., 2008). Following these concepts of multifunctional use, sustainable seafood production shows an enormous economic potential in offshore areas (Buck et al., 2008).

Shellfish aquaculture, particularly oyster and mussel cultivation, is a good example for extensive production and has become very attractive (Gibbs, 2004). These candidates do not require artificial feeding

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Fig. 1. Map of the German Bight showing all test sites: *Butendiek* (BD), *Helgoland* (HE), *Wurster Arm* (WA), and *Nordergründe* (NG).

(Ferreira et al. 2009; Garen et al., 2004) and as essential bio-extractive organisms can even improve water quality in marine systems (Ferreira et al., 2009; Rose et al., 2010). A feasibility study on open-ocean aquaculture by Buck (2002) identified the following extractive candidates as most suitable for the North Sea: sugar kelp (*Laminaria saccharina*/*Saccharina latissima*), dulse (*Palmaria palmata*), blue mussel (*Mytilus edulis*) and two oyster species, the Pacific oyster (*Crassostrea gigas*) and the European flat oyster (*Ostrea edulis*). As oysters represent high-value products and realize high prices on the market, compared to other shellfish (FAO 2011; Troell et al., 2009), these organisms seem to be ideal candidates for offshore aquaculture. However, techniques for offshore cultivation of oysters have not been developed yet, as over centuries, different forms of oyster cultures were only developed in coastal areas (Burbridge et al., 2001).

Consequently, no information is available on growth performance and fitness of oysters farmed in offshore areas, which experience high-energy environments. From the biological perspective the present study aims to assess whether offshore oyster cultivation offers a promising potential regarding growth performance in rough conditions.

This is the first study focusing on cultivation and subsequent performance characteristics of the Pacific oyster (*C. gigas*) and the European flat oyster (*O. edulis*), exposed to offshore farming conditions. In two experiments (2004 and 2007) we examined growth performance, condition and survival of oysters and analyzed site-specific criteria for the cultivation at offshore sites in the North Sea (Germany).

2. Materials and methods

2.1. Origin of test animals and description of study sites

Juvenile oysters were obtained from commercial hatcheries. For the sampling season 2004 *O. edulis* was produced at the Danish Shellfish Centre (Denmark) in September 2003 (observed as veliger) and *C. gigas* at Guernsey Seafarms (UK) in July 2003. For the sampling season 2007 oysters of *O. edulis* were produced in April 2006 (observed as veliger) at Bømlo Skjell A. Musling (Norway). *C. gigas* spat (produced in July 2006) was obtained from Guernsey Seafarms as well. Initial size classes (shell length) of juvenile oysters were 10–20 mm in 2004 and 20–30 mm in 2007. For the cultivation under offshore conditions juveniles of both species were transferred to the test sites in April 2004 (preliminary experiment for site selection) as well as in April 2007 (main experiment).

In the preliminary experiment oysters were cultivated in three different areas of the German Bight (Fig. 1). These study sites are characterized by various hydrographic features, such as depth, condition of the sea bottom, wave exposure, current velocity and significant wave heights (BSH 2011; Mittelstaedt et al., 1983), which are shown in Table 1. The site-specific conditions of these areas were chosen to fulfill the offshore-criteria in terms of a high-energy environment following the definition of Ryan (2005). Two test sites were set up within the areas of projected wind farms to underline the idea of the multiple-use concept. Furthermore, accessibility to sample and service the sites was also taken into account but of secondary relevance.

The test site *Butendiek* (BD) was located 15 nautical miles (nmi) west of the northern tip of the North Frisian island of Sylt (54° 59,1´ N; 007° 54,4´ E). Water depth was approximately 16 m at mean high water (MHW). This site was chosen because it is located within the area of the planned wind farm “Butendiek”. The rounded metal piles of a former research platform of the Federal Maritime and Hydrographic Agency (Buck et al. 2008) provided an adequate fixed position within an offshore (high-energy) environment, and were used as a holding device for the oysters. A permit for the utilization of the study site was obtained in March 2004. Cultures were mounted at 4 m depth (high tide). The test site *Helgoland* (HE) was set up northeast of the island of Helgoland (54° 11,4´ N; 007° 53,0´ E). Water depth at site was approximately 6 m at MHW. Cultures were mounted to a metal frame at 4 m depth of water (high tide). The metal frame was moored on the seabed and co-used as a test site for the settlement of *Mytilus edulis* post-larvae. Despite the fact that this test site was about 150 m off the island of Helgoland, it can be considered as an offshore site due to the typical conditions that characterize this location (strong currents, high waves, good water quality, deep enough for submerged cultures (Barnaby, 2006)) and the fact that Helgoland is defined as an offshore island at all. The test site *Wurster Arm* (WA) was located in the outer Weser estuary (53° 40,7´ N; 008° 24,5´ E). Water depth at the site was approximately 8.5 m at MHW. Cultures were mounted at 1.5 m depth below a navigation buoy of the Water and Shipping Agency (WSA) Bremerhaven and were therefore independent of tidal influence. The main experiment started in 2007 and cultivation was carried out at a

Table 1
Site-specific conditions and classification of the four test sites.

Test site	Code	Year	Distance to coast [nmi]	Classification	Depth at MHW [m]	Sediment type at sea bottom	Sediment load of water column	Significant wave height [m] [a]	Wave exposure	Current velocity [m/s] [a,b]	Max. daily tidal current velocity [m/s] [a]
Butendiek	BD	2004	17	Offshore	14,8	Sand	Low	0.4–5.1	Exposed	0.2–0.6	0.32
Helgoland	HE	2004	25	Semi-offshore	6,0	Sand	Low	0.5–4.0	Exposed	0.1–0.7	0.30
Wurster Arm	WA	2004	3	Nearshore	8,5	Mud (clay)	High	0.2–1.8	Moderate	0.3–0.7	0.45
Nordergründe	NG	2007	9	Offshore	11,5	Sand	Moderate	0.5–5.0	Exposed	0.2–0.8	0.34

nmi: nautical mile, MHW: mean high water.
[a] BSH 2011.
[b] Mittelstaedt et al. 1983.